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Fertilizer Quality Monitoring System in the Supply Chain based on Wireless Sensor Networks

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Abstract.

Several farmers are reported to be utilizing substandard fertilizer as a result of supply chain concerns such as inappropriate storage and adulteration by dealers, resulting in soil infertility, low yields, water pollution, and biodiversity loss. The purpose of this research is to demonstrate the construction of a wireless sensor network system capable of collecting and analysing data from each stage/point in the supply chain, as well as communicating status updates and recommendations to important supply chain partners. The system collected and evaluated data from each stage and point in the supply chain, and it was able to provide status information and advice to the major supply chain players. This enables the detection of changes in the quality of fertilizer prior to its delivery to farmers, allowing for the implementation of appropriate measures. Test results are wirelessly transmitted to the monitoring software's base station server for analysis, display, and storage through a communication module. The host server is comprised of an interpretation program that is used to receive, process, and display data in real time. Users may obtain information from the base station server through their mobile phones. The remote server of the base station maintains certified fertilizer parameter values for each new batch and the status of reported fertilizer parameter values for each warehouse and provides the report and associated advice to the server and users, respectively. On the one hand, users may use predefined instructions on their mobile phones to seek information about chemical fertilizers and obtain real-time fertilizer nutrient quality metrics. On the other hand, the system notifies the server and users of the report and any associated recommendations. The project's results have been positive, and the project's objective is to aid farmers in making better-informed decisions and boosting agricultural yields via the use of technology.

Keywords: Fertilizer quality; monitoring system; supply chain; wireless sensor networks.

Introduction

A fertilizer is a chemical-based material that is used to improve plant growth and fertility. It may be natural or manufactured. It is also referred to as any natural or synthetic substance (other than liming materials) applied to soils or plant tissues to provide one or more plant nutrients required for plant development [1, 2]. Inorganic fertilizer is one of a limited number of agricultural technologies with enormous promise for increasing the productivity of impoverished smallholders, allowing them to gain income, amass assets, and put themselves on a route out of poverty economically [3, 4]. Tanzania, like the rest of Sub-Saharan Africa, is heavily reliant on imported fertilizer [5].

NPK (nitrogen, phosphorous, and potassium) fertilizers are three-component fertilizers that provide nitrogen, phosphorous, and potassium [6]. NPK ratings are three digits separated by dashes that describe the chemical content of fertilizers (e.g., 10-10-10 or 16-4-8). The first number denotes the amount of nitrogen in the product, while the second denotes phosphorous (P2O5) and the third, potassium (K2O). Fertilizer grade or analysis is the weight percent of available nitrogen (N), phosphate (P2O5), and potash (K2O) in the material, expressed in the order N-P2O5-K2O. For example, 10-20-10 indicates that the material is 10 percent N, 20 percent P2O5, and 10 percent K2O by weight. The fertilizer ratio is the weight percent of N-P2O5-K2O and is calculated by dividing the three numbers by the smallest of the three. Again, using 10-20-10 fertilizer as an example, the ratio is 10/10-20/10-10/10 = 1-2-1. A 23-kilogram bag of fertilizer labeled 16-4-8, for example, contains 3.6 kg of nitrogen (16% of 23 kg), 0.9 kg of phosphorous (40% of 23 kg), and 1.9 kg of potassium (80% of 23 kg).

The movement of fertilizer and related information from production to the end user through the distribution channels is known as the fertilizer supply chain [7]. Fertilizer products may now be manufactured and supplied to the ultimate customer thanks to supply chains that extend all the way to the retail level [8]. As a result, a quality check of fertilizer should be conducted at any point along the retail chain to weed out substandard or counterfeit fertilizer. Adulteration of fertilizers involves the practice of adding extraneous material to a standard fertilizer to lower its quality. When a fertilizer contains harmful or deleterious ingredients or unwanted crop or weed seeds in sufficient quantities to harm the plant when applied according to label directions, its composition differs from that given on the label, and useless materials such as salt or sand are added to it, it is said to be adulterated [9]. Inorganic fertilizers are a new technique to provide crops with the nutrients they need while also increasing their output. [10, 11].

Numerous farmers are found to be using substandard fertilizer as a result of supply chain issues such as improper storage and adulteration by dealers, resulting in soil infertility during cultivation, low yields, water pollution, and biodiversity loss. Consignments of imported inorganic fertilizer may be contaminated with seeds, soil, and other plant or animal material, thereby introducing dangerous alien pests and diseases into the country. Contamination can occur at any point along the supply chain, including the manufacturer, logistics, container loading, and the container transporting the product to the end user.

In Tanzania, conventional instrumental analysis is used to determine the nutritional quality of NPK chemical fertilizers, which are then retrieved from the field for laboratory assessment [12]. In general, these procedures need a large investment in laboratory analytical gear, as well as extensive maintenance, training, and highly experienced personnel. Because there is no ICT-based instrument to inspect fertilizer quality, private sector executives and government officials have expressed concern about quality controls executed manually as a result of resource constraints, such as a scarcity of inspectors. Testing time, equipment investment, complex operation, dependency on auxiliary equipment, higher testing expenditures, and the inability to use this approach in distant places are all disadvantages of this approach. For example, the quality of fertilizer can be checked by looking at the business name, expiration date, and product composition on fertilizer bags. Due to a lack of reliable equipment for monitoring fertilizer in the warehouse and providing information automatically and on demand, untrustworthy vendors have used this loophole to offer phony fertilizers to farmers. As a result, real-time assessment of the nutritional content of NPK chemical fertilizers in the supply chain is becoming more prevalent [13].

The novelty of this study is the development of a wireless sensor network system that can capture and analyze data from each stage/point in the supply chain, as well as send status updates and suggestions to key supply chain partners. It should be able to get exact real-time data in order to assist regulatory bodies in taking action when counterfeit or sub-standard fertilizers are identified. This will enable the detection of changes in fertilizer quality and the adoption of appropriate steps prior to the fertilizer's being distributed to farmers. The system will be used to monitor and manage fertilizer quality from the point of import to the point of sale. At the import level, WSNs will be deployed at the import level to capture and train the system on recognized fertilizer quality values. The same calibrated WSN will be installed at each level of the supply chain, such as warehouses, to compare the quality of fertilizer to that captured at the import level. When comparing current data to previously established quality indicators, the WSN will be able to determine the level of quality decline..

1. Related Works

Numerous research exists that demonstrates how fertilizers contribute to increasing agricultural yields over time [13–15]. Reference [16] developed an automated, low-cost Internet of Things (IoT)-based fertilizer notification system for smart agriculture. By developing a unique Nitrogen-Phosphorus-Potassium (NPK) sensor with a Light Dependent Resistor (LDR) and Light Emitting Diodes, the article demonstrated an IoT-based system (LED). Colorimetric analysis was utilized to monitor and assess the nutrients in the soil. However, this study only looked at fertilizer data from a few areas of farming and didn't take the supply chain into account.

A mobile equipment system has been studied for measuring soil fertility parameters from a field vehicle. The reference [17] developed a wireless sensor network-based prototype tractor-mounted field monitoring system for measuring soil nitrate levels in fields. The system was evaluated in the laboratory and in the field. It consists of a soil sampler, an extraction unit, a flow cell, and a controller. Initially, the soil sampler was equipped with a chain saw blade and a belt conveyor to collect and transport samples of known volume and density to the extraction and analysis equipment. However, during field testing, various mechanical and electrical issues were discovered, such as blockage of the extractor outlet with plant waste, which led to unacceptable levels of noise in the electrode signal. Additionally, an automated field monitoring system that has the ability to function as a real-time soil nitrate analyzer was recently enhanced with the addition of an automated sampler that offers exact mass estimations of the sample. On the other hand, mobile sensing of soil chemical characteristics by reflectance spectroscopy appears to be less promising. Some positive results have been reported, but there are still problems with calibration and accuracy that haven't been solved.

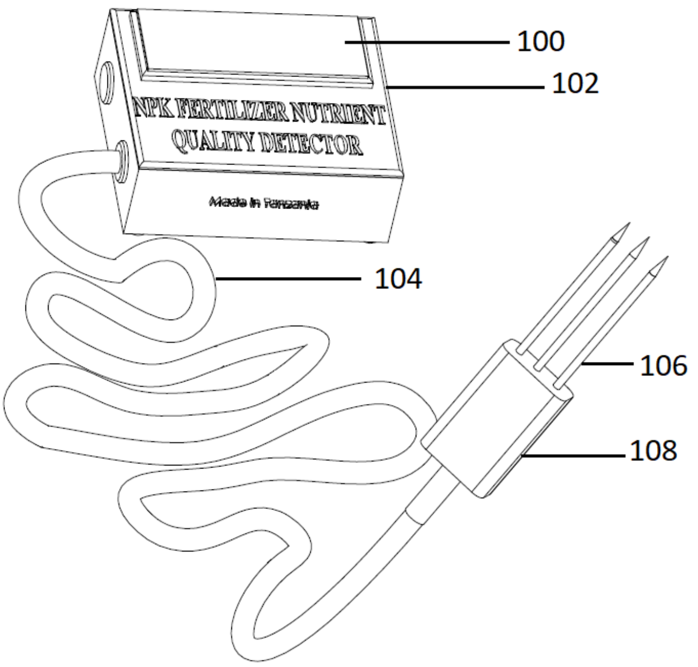
To address the aforementioned issues, an enhanced organic fertilizer mixer based on IoT technology was created that is capable of remotely monitoring fertilizer production and providing updates and notifications to employees on when to add additional material to the mixture [18]. In [19], an overview of soil macronutrient sensing for precision agriculture was given. Reference [20] used a color sensor to assess the soil pH and nutrient levels, namely the presence of nitrogen, phosphate, and potassium. However, the method did not inform farmers of the type of fertilizer to use for each nutrient.

A recent research study [21] described the construction of a website-based traceability information system for the supply chain of subsidized fertilizer. A manufacturer may identify product lots and their links to batches of raw materials, processes, and product delivery using the traceability system. However, the system is missing mechanisms for measuring and monitoring fertilizer quality across the supply chain. As a result, addressing the issue of evaluating the quality of fertilizer along the supply chain remains crucial.

2. Materials and Methods

3.1 Hardware structure design scheme

As illustrated in Figure 1, the NPK and pH nutrient sensors are mounted to the panels of the data acquisition device with an aluminium enclosure. A signal conditioning circuit is included in the NPK and pH sensors to process the output signal so that it is acceptable for the next stage of operation. It is made up of an analogue-to-digital converter (ADC) that is connected to a linear amplifier. The signal conditioning circuit performs signal amplification (opamp), filtering, protection (Zener & photo isolation), linearization, and error compensation. High current and high voltage are protected from causing harm to the circuit's key components. The cable connects the NPK and pH sensors to the data acquisition device. The data acquisition device is composed of a microcontroller, a communication device, a liquid crystal display (LCD) for displaying measured data in real time, and various electronic components. The control circuit is enclosed in a waterproof aluminum casing.



100-Liquid crystal display (LCD); 102-Fertilizer nutrient detector; 104-Cable; 106-Signal conditioning unit
Figure 1: Fertilizer nutrient quality detector

This instrument can measure the nitrogen, phosphorus, potassium, and pH levels of chemical fertilizers. The recording time and the test sample are automatically saved with the display feature. The LCD panel displays the stored data (test sample, pH, and different NPK nutrient results). The data can be transferred to remote base station monitoring software for analysis, storage, and real-time display. The interpretation program may receive data from monitoring software, evaluate it, and provide a report to the server and users with suggestions. Experts and regulatory agencies can specify fertilizer quality indicators like macronutrient composition parameter values and pH with reference to the applicable national standards.

NPK and pH, physical parameters, and fertilizer identity information (batch number, manufacturing date) are all collected by a data acquisition device in the system. Secondly, the analysis and interpretation component deals with receiving, processing, and displaying data in real time. Lastly, a communication module delivers data from sensors and RFID readers to a remote server for analysis, display, and storage. This system's base station remote server stores certified fertilizer parameter values for each new batch and fertilizer parameter status reports for each warehouse. Sensor node data is collected and processed by the base station remote server. The data is then stored, reported on, and displayed on a real-time basis. Monitoring software provides data to the base station remote server, which processes it and delivers the report and relevant suggestions to the server and users. Chemical fertilizer data may be requested via mobile phones using predefined instructions and received in real time while the system also transmits the report and relevant suggestions to the server and users. This is a two-pronged approach.

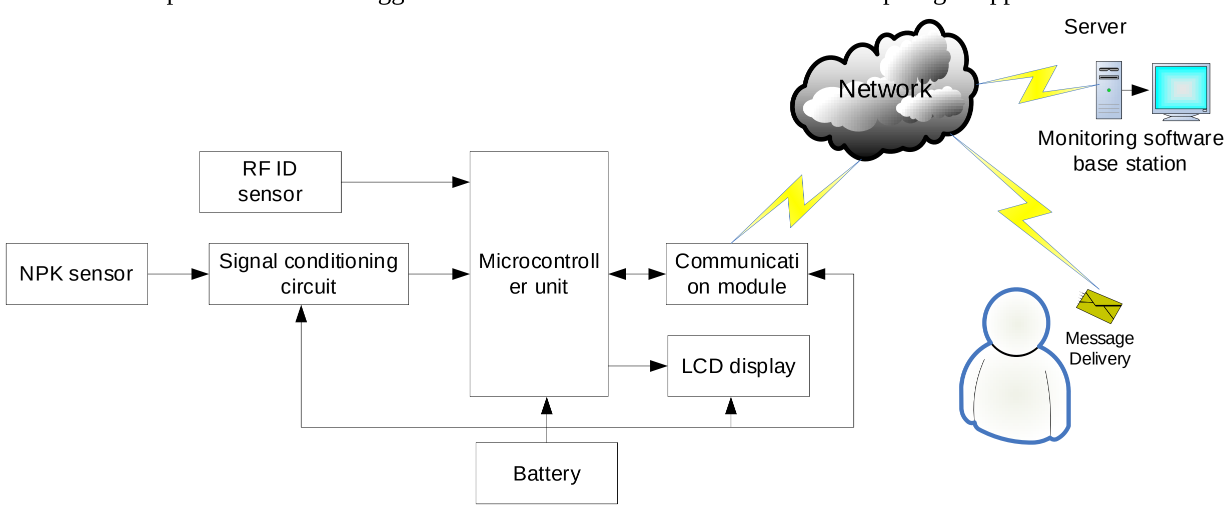


Figure 2: Block diagram of NPK fertilizer nutrient quality detector

As seen in Figure 2, the control circuit consists of an RF ID sensor, an NPK sensor, and a pH sensor connected to a signal conditioning circuit and a microcontroller. The system's data acquisition and processing are performed by an ATmega16L microcontroller. The ATmega16 features an advanced RISC architecture, 113 instructions, 32 general-purpose registers, and performance up to 16 MIPS at 16 MHz. Other features include two-cycle hardware multipliers, an 8-channel 10-bit Analog to Digital Converter (ADC), 32 programmable Input/Output (I/O) ports, a 16KB system programmable watchdog timer with an independent on-chip oscillator, power on reset, and programmable power failure detection. The microcontroller chip then generates control signals in response to a comparison with standard parameters in order to show measured data in real time on the LCD screen and transmit measured data to the wireless network through the communication module. The produced data and control signals are pooled and transferred through WiFi to a gateway linked to the host computer's base station. Data and control signals generated are aggregated and transmitted through the WiFi network to the gateway, which is connected to the host computer base station. The system is powered by five 5V DC batteries.

The gateway accepts command packets, preprocesses and analyzes data from sensor nodes, and then transmits it to the host computer base station. The gateway communicates with the base station through a WiFi connection. The monitoring software is placed on the host computer's base station and is used to show results and deliver brief messages to users. Users can obtain measured data by installing a mobile application on their smart phones. In light of the communication requirements between the host computer and its owners, utilizing the GSM network not only saves money, but also increases the communication range and area. The host computer base station is comprised of interpretation software that reads data from monitoring software, analyzes it, and transmits the report and associated recommendations to the server and users. The data is saved in a database for future usage and forecasting, is presented in real time, and may be emailed to users. The base station remote server stores certified fertilizer parameter values for every new batch and reports the status of the fertilizer parameter values for every warehouse and sends the report and related suggestions to the server and users, respectively. Users, on the other hand, can request information about chemical fertilizers from their mobile phones by using predefined commands and receive fertilizer nutrient quality parameters in real time. On the other hand, the system sends the report and related suggestions to the server and users.

One of the most interesting aspects of this system is that its gadgets may operate without any human or human-computer interaction. Wi-Fi, and low-powered long-range radio modules have all contributed to the development of new systems that can forecast and monitor a wide variety of factors. Sending and receiving data via a network is done by the radio module, which has a unique numeric identifier, or IP address.

3.2 Software system design

This project's embedded software aimed to create a simple, user-friendly interface for interfacing with the main unit. The program was separated into various functions (subroutines) according to the tasks throughout the development process to reuse code and therefore make the program resilient and fast to run. Furthermore, the source code was documented to facilitate future revisions and upgrades. After finalizing the source codes, they were compiled and debugged to eliminate any potential mistakes. The ability of the user to engage with the fertilizer quality monitoring system is a key feature. We opted to employ Wi-Fi between the mobile application and the main printed circuit board (PCB).

The ESP8266 Wi-Fi module was utilized to link the PCB wirelessly. The ESP8266 Wi-Fi Module is a self-contained SOC with an integrated TCP/IP protocol stack that can connect any microcontroller to a Wi-Fi network. The ESP8266 may either host an application or offload full Wi-Fi networking capabilities to another CPU. If both devices are linked to the same wireless network, this Wi-Fi module may interact with them over Wi-Fi. This was performed using the Wi-Fi module, which acts as a wireless access point for other devices or connects to another access point by running its own web server. The module was designed to serve as a connection point for other devices. In this mode, the user may connect their device to the access point and navigate to an IP address where they can set the name of the wireless network to which the system should be connected as well as the password for that network. Following this stage, the Wi-Fi module will again create a server, but this time it will be on the wireless network that the user has selected.

Figure 3 shows the graphical user interface (GUI) which monitors and transfers the real-time data to an Android-based smartphone via the internet. Additionally, the GUI stores real-time data in an excel sheet with the date and time for further analysis. The data displayed in the GUI in numerical and graphical form helps in quick understanding and decision-making.

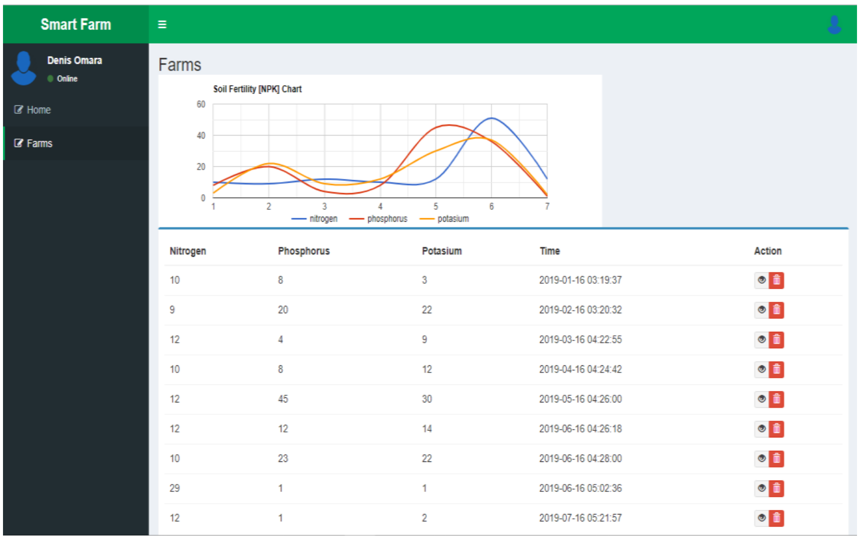


Figure 3: Monitored data of NPK from graphical user interface

The sensitive data handled by the software system was considered in our design. These data pieces are any user information and any private network credentials used by the wireless module on the PCB to connect to the local private network in our system. Encryption using cipher-block chaining and PKCS5 padding is used in the implementation. Encryption and decryption of files are performed by applying a cipher to the IO streams. When reading or writing encrypted files, the static methods of the Crypto class can be utilized.

3. Results and Discussion

Data from each stage/point in the supply chain was collected and analyzed, and the system was able to transmit status information and advice to the primary supply chain participants. This allows for the identification of changes in the quality of fertilizer before it is delivered to the farmers, so that relevant steps may be implemented. The sensor nodes were equipped with NPK and pH sensors to monitor nitrogen, phosphorus, potassium, and pH, respectively. The system was validated by placing two sensor nodes in the wholesale distributor's warehouse and two sensor nodes in the retail agro-warehouse.

Sample NPK fertilizer bags were tagged with RF ID and monitored by the system for a 24-hour period. Two months later, the same bags were measured by the system at the retail store. Real-time data collection and analysis of fertilizer quality factors like NPK and pH were used to compare the findings. The findings are quite encouraging and can be used as a diagnostic tool or to identify temporal patterns. After analyzing the trial data, it was determined that the amounts of macronutrients nitrogen, phosphorus, and potassium, as well as soil pH, varied consistently but not significantly.

Figure 4 shows the wide range of nitrogen levels found in fertilizer sample bags. In Figure 5, it can be shown that the average phosphorus content varied between 28.0 and 36.0 mg/kg. Potassium monitoring data is shown in Figure 6. Potassium levels were found to be stable on average, ranging between 24.0 and 26.0 mg/kg. As seen in Figure 7, the system was examined for pH responsiveness and long-term stability. Fertilizer sample bags were found to be somewhat alkaline, ranging between 7.4 and 8. The pH of the studied solution is typically steady throughout time, and no variations were observed.

Determining the nitrogen, phosphorus, potassium, and pH contents of a presented technology can provide insight into how well it performs in relation to its intended usage. A nutrient analysis determines the average nutrient concentration (mg/L) for all nutrients examined. In an agricultural setting, understanding the quality of fertilizer nutrients can assist farmers in avoiding the purchase of counterfeit fertilizer, hence minimizing loss.

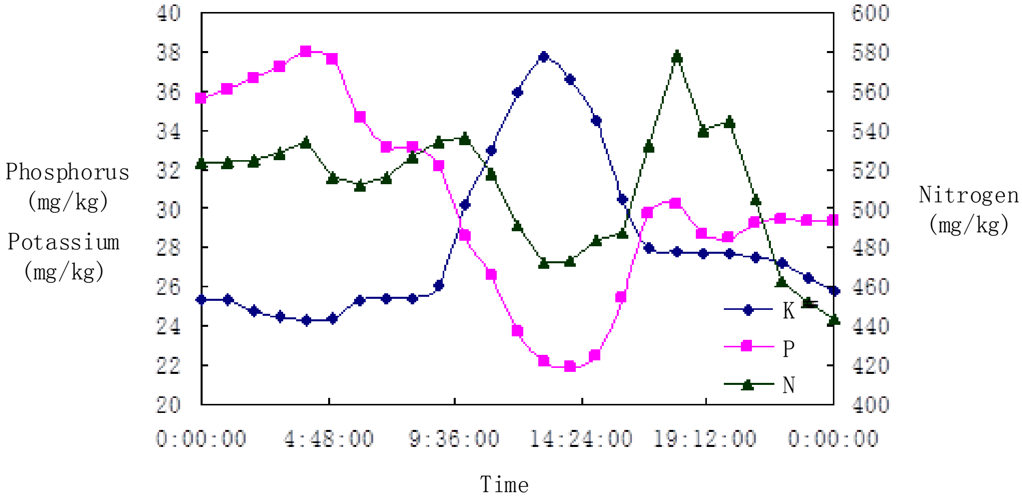


Figure 4: Monitored data of nitrogen

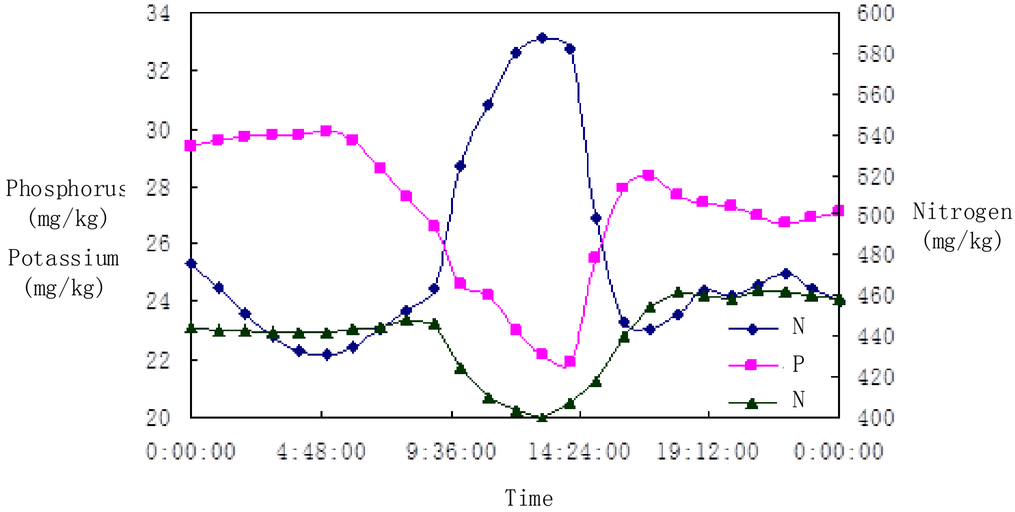


Figure 5: Monitored data of phosphorus

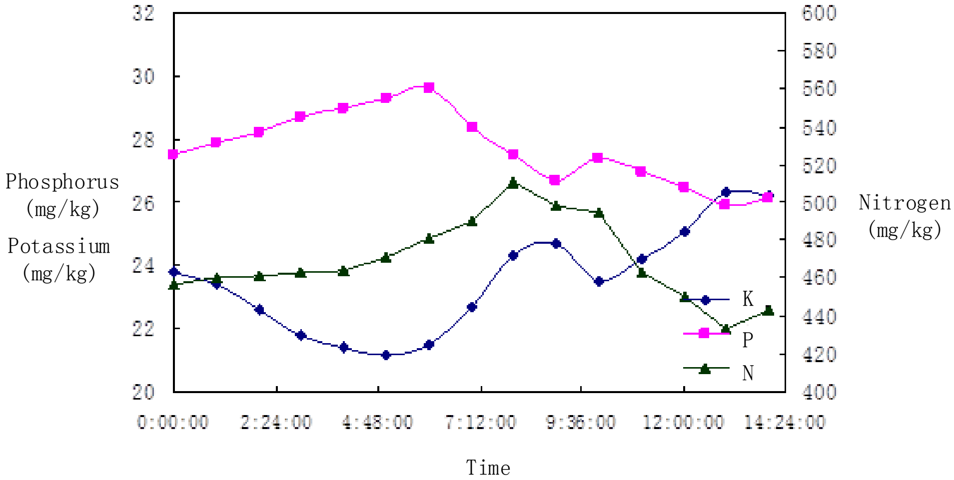


Figure 6: Monitored data of potassium

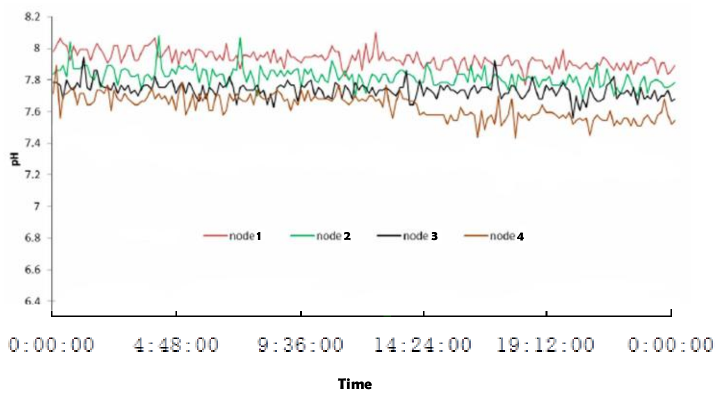


Figure 7: Monitored data of pH

4. Conclusions

The presented system can collect and analyze data at each stage/point in the supply chain, as well as communicate status updates and recommendations to critical supply chain partners. It can obtain precise real-time data to aid regulatory authorities in acting when counterfeit or substandard fertilizers are discovered. This system continually monitored and reported on the fertilizer's NPK and pH readings. Test results are sent to the monitoring software base station server wirelessly through a communication module for analysis, presentation, and storage. The host server consists of interpretation software for receiving data, processing, and real-time display. Users can access the information from the base station server through their mobile phones. The base station remote server stores certified fertilizer parameter values for every new batch and reports the status of the fertilizer parameter values for every warehouse and sends the report and related suggestions to the server and users, respectively. Users, on the other hand, can request information about chemical fertilizers from their mobile phones by using predefined commands and receive fertilizer nutrient quality parameters in real time. On the other hand, the system sends the report and related suggestions to the server and users. The numerous test findings given provide a concise description of the implemented system's functionality. We conclude that the system's and device's overall functionality is satisfactory.

The project's results are favorable and are aimed at helping farmers make more informed decisions and increase agricultural yields via the use of technology. The study's findings indicate that monitoring fertilizer quality across the supply chain requires an integrated approach to fertilizer distribution management. Additional training is necessary for personnel testing of fertilizer at each stage/point in the supply chain. It is vital that farmers and local agro-merchants have access to the tested system. This requires adequate training and the provision of the equipment necessary to conduct such tests. Future system enhancements will necessitate system expansion through the integration of other sensors and further development of the NPK sensor.

Conflict of Interest

The author declares that he is unaware of any conflicting financial interests or personal ties that would appear to have influenced the work described in this publication.

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Authors' Biography

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Intelligent technologies, embedded systems, and wireless sensor networks are among his research interests.